

# **Radiative Transfer in Seagrass Canopies**

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## **LONG-TERM GOAL**

The overall objective of this study is to develop models of radiative transfer for optically shallow waters with benthic substrates colonized by submerged aquatic vegetation (SAV). Such models will enable the quantitative prediction of upward spectral radiation from vegetated seabeds, thereby permitting the use of optical remote sensing to retrieve bathymetry, to search for submerged objects of anthropogenic origin and to map submarine resource distribution and abundance in coastal waters. These models will also have important applications for predicting irradiance levels within SAV canopies, a task necessary for accurate determination of light requirements and photosynthetic productivity of these ecologically important, but increasingly vulnerable coastal resources.

## **SCIENTIFIC OBJECTIVES**

The objectives of this study are to develop radiative transfer models of seagrass canopies *in situ* that include (i) canopy architecture (e.g., layers created by multi-species communities), (ii) height above the bottom, (iii) impacts of water motion and (iv) bottom reflectance from the canopy/substrate complex back into the water column.

## **APPROACH**

The work involves development of mathematical descriptions of canopy architecture (plant density & vertical biomass distribution), reflected upwelling radiance, and light absorption and photosynthesis within SAV canopies from direct field observations and laboratory measurements. A system of coupled equations generated from these measurements will be solved for specific scenarios of canopy structure and water column optical properties to evaluate the effect of spectral quality and flux density of the downwelling irradiance on benthic spectral radiance and whole canopy productivity. Radiative transfer modeling within the canopy began with the simple model first proposed by Monsi and Saeki (1953) which provides an excellent first-order description of radiation interception within closed (horizontally homogeneous) canopies, and is being extended to include the effects of leaf orientation and plant shape using elliptical models and more open architectures using the approach pioneered by Norman and Welles (1983) for terrestrial plant systems. Model predictions of benthic reflectance and water-leaving radiance are tested against *in situ* measurements to evaluate the degree of agreement between theory and observation. A spectral photosynthesis model, based on leaf absorption is being used to explore the effects of a range of water columns with different inherent optical properties and canopy architectures on photosynthesis, whole plant carbon balance, shoot density and depth distribution.

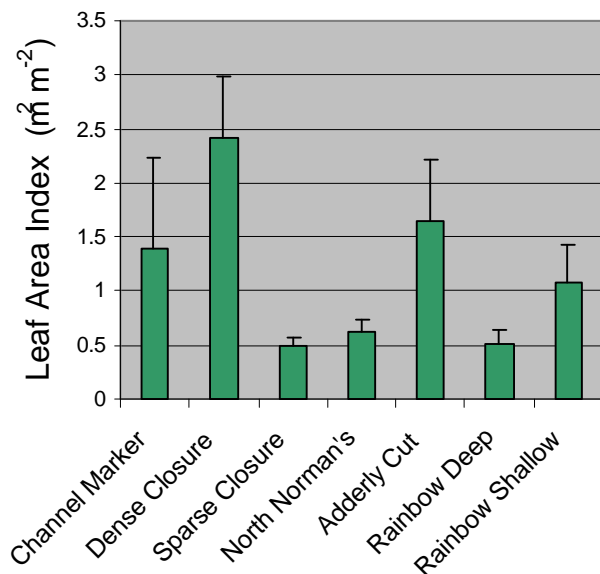
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## WORK COMPLETED

In the first year, canopy architecture of the eelgrass meadow growing at Del Monte Beach, Monterey, California, was characterized and a preliminary model of vertical canopy architecture was developed (Zimmerman and Mobley 1997a; b) and expanded in Year 2 to include the effect of flow on canopy architecture and spectral distribution of irradiance within the canopy (Zimmerman and Mobley 1997c; Maffione and Zimmerman submitted; Zimmerman and Maffione submitted).

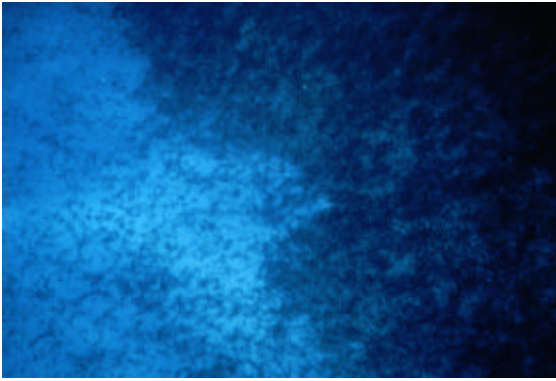
We participated in the first CoBOP expedition to Lee Stocking Island (LSI), Bahamas in May and June 1998. Our efforts at Lee Stocking Island in 1998 focused on characterization of the inherent optical properties (IOP's) of leaves of the seagrass *Thalassia testudinum*, and vertical architecture of the seagrass canopy in preparation for developing a thorough understanding of radiative transfer within, and reflectance from, canopies of submerged benthic vegetation. Leaf absorbance and reflectance were measured in the laboratory using a spectrophotometer fitted with an integrating sphere. Canopy architecture (shoot density, leaf size-frequency distribution, leaf orientation) was measured *in situ* using SCUBA. Post-expedition activities focused on analysis of the data collected at LSI, particularly with regard to calculations of corrected leaf absorbance, reflectance and absorptance spectra from the different sites.

We also participated in two short expeditions to Monterey Bay in collaboration with CoBOP P.I.s M. Allison, D. Burdige, F. Dobbs, R. Maffione, and C. Stephens to investigate the optical properties of Monterey Bay benthic habitats. Data from these efforts are still being processed.



**Figure 1. Leaf area indices for different locations around Lee Stocking Island, Bahamas.**

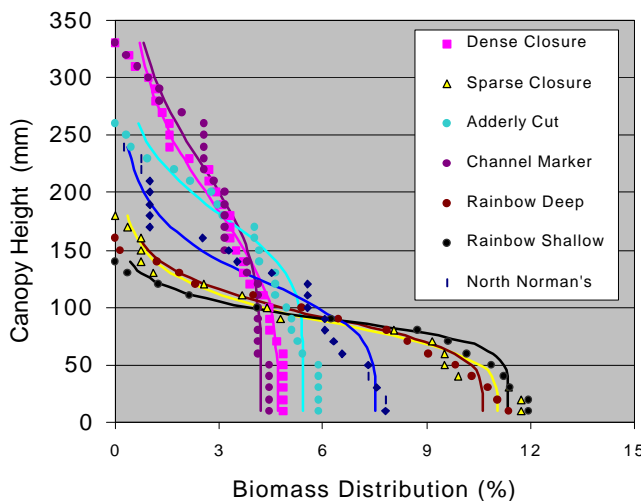
Our modeling results were presented at the 1998 AGU-ASLO Ocean Sciences meeting in San Diego, CA, and a summary presentation of Year 2 efforts was presented at the CoBOP Annual Workshop in September 1998.



**Figure 2.** Underwater photograph of the transition between dense and sparse seagrass coverage at the Closure Site, Lee Stocking Island, Bahamas.

## RESULTS

A wide range of canopy architectures were quantified, ranging from sparsely vegetated areas populated by plants of short stature to dense meadows composed of relatively large plants. Although shoot density was remarkably constant among sites ( $\sim 250$  shoots  $\text{m}^{-2}$ ), leaf area index ( $\text{m}^2$  leaf area  $\text{m}^{-2}$  substrate) varied almost 5-fold among sites (Fig. 1). Often these regions were in very close proximity to each other, as in the transition between dense and sparsely vegetated patches at the closure site (Fig. 2). The dense closure site supported 350 shoots  $\text{m}^{-2}$ , while the sparse area supported almost 300 shoots  $\text{m}^{-2}$ . Thus, shoot size, as defined by leaf length and number of leaves was the principal factor determining differences in leaf area. This difference in plant size produced very different patterns of vertical biomass distribution among sites (Fig. 3).

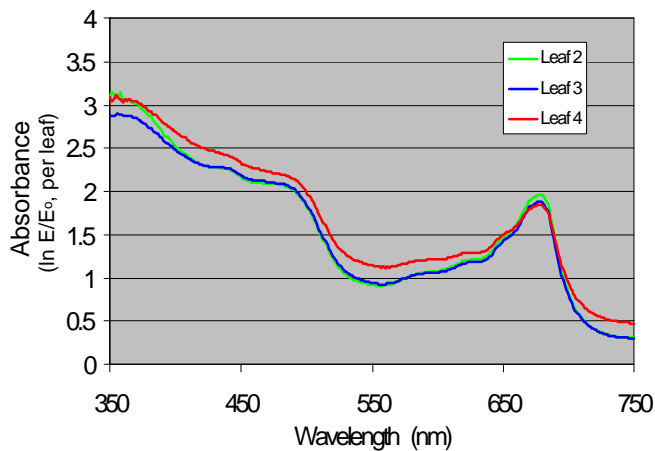


**Figure 3.** Vertical biomass distributions of *T. testudinum* canopies at several sites around Lee Stocking Island. Curves are logistic functions fit to the data.

In contrast to the differences observed in canopy architecture, leaf IOPs were more consistent across locations and leaf age classes. Removal of epiphytes revealed almost no difference in the absorption or reflectance spectra among leaves of different age classes (Fig. 4). Epiphyte abundance increased with leaf age, and attenuate as much as 50% of the light when fouling was heavy (data not shown).

The leaf IOPs and canopy architecture data are currently being formulated into a model that predicts radiative transfer through the canopy, as well as the benthic albedo of vegetated substrates. Using this model, we have calculated the reflectance spectrum of a hypothetical benthic substrate containing various mixtures of seagrass and pure carbonate sand. The addition of seagrass to

the pure sand spectrum lowered the overall albedo of the benthic substrate and altered the shape of the spectrum (Fig. 5). 4<sup>th</sup> derivative analysis of these spectra revealed a consistent relationship between the fraction of seagrass in the spectrum and the amplitude of the 4<sup>th</sup> derivative at several wavelengths, especially those in the blue region of the spectrum ( $< 550$  nm) that are most useful for shallow water applications (Fig. 6). We will continue developing these algorithms as a means of identifying seagrass signatures and determining the relative abundance of seagrass in data sets of benthic reflectance. These algorithms and radiative transfer predictions from the modeling efforts are under evaluation by extensive



**Figure 4.** Mean absorption spectra of *T. testudinum* leaves cleaned of epiphytes, by age class. Leaf 4 is oldest.

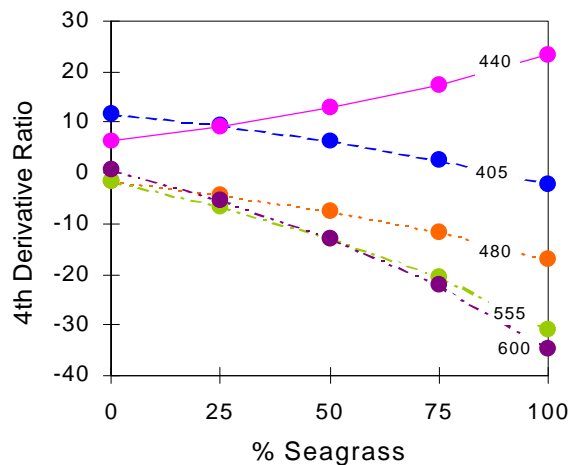
*in situ* observations during subsequent CoBOP field efforts to Monterey Bay and LSI.

## IMPACT/APPLICATIONS

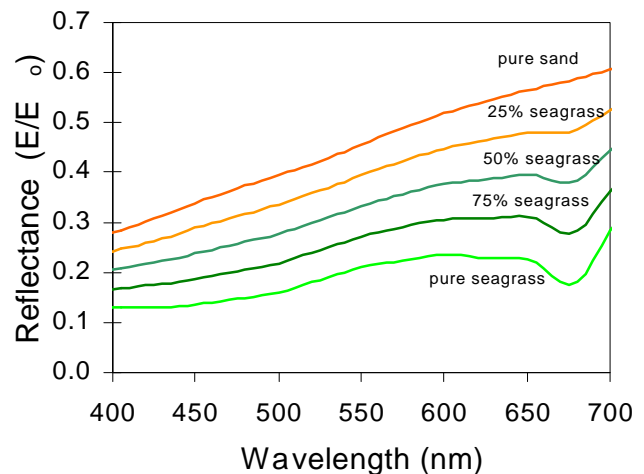
This study is providing critical data sets required and models required to understand the dynamics of radiative transfer in optically shallow waters characterized by a variety of benthic substrates, including submerged aquatic vegetation. Such information is critical for the evaluation of remote sensing algorithms designed for shallow water applications including the search for and identification of anthropogenic objects and environmental resource monitoring and mapping applications.

## TRANSITIONS

This work has attracted considerable attention from seagrass management agencies and other scientists interested in coastal water quality. Theoretical calculations on the effects of sediment loading on the submarine light environment and seagrass photosynthesis, performed in collaboration with R. Maffione, were presented at a workshop sponsored by the US Army Corps of Engineers Waterways Experiment Station. The Army Corps is now re-thinking their plans for monitoring coastal environments and evaluating the effects of dredging operations on coastal SAV populations to include spectral irradiance as a result of our work. In particular, this has already led to the modification of a



**Figure 5.** Reflectance spectra of various mixtures of seagrass and sand, ranging from pure seagrass to pure sand.



**Figure 6.** 4th derivative amplitudes normalized to the isobestic wavelength of minimum change (465 nm) can be related to the fraction of seagrass

dredge monitoring program in Laguna Madre, Texas to include measures of spectral backscattering and irradiance, under the supervision of R. Maffione.

## **RELATED PROJECTS**

The efforts described above are being performed in collaboration with other CoBOP participants to produce measurements of light field characteristics within and above seagrass meadows and to develop more realistic light field models for shallow benthic canopies. The observed data will be compared to model calculations as part of the closure experiments fundamental to the CoBOP program.

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